3. TWO-DIMENSIONAL NUMERICAL MODELING ACTIVITIES

3.1 Flow Model Development

During fiscal year 2005, the conceptual model described in Section 2 was implemented in a two-dimensional, steady-state numerical flow model. The computer codes used to develop the two-dimensional flow model were the MODFLOW-2000 (Harbaugh et al. 2000) groundwater flow simulation code, the PEST (Doherty 2005) parameter estimator, and the Groundwater Modeling System (GMS) (BYU 2003) pre- and post-processor and data analyzer. MODFLOW is an industry standard groundwater flow simulation code developed by the USGS. MODFLOW-2000 is the latest version and incorporates many new features.

PEST is a robust parameter estimator that is designed to automatically adjust the parameters in any model over a series of runs until model-generated results fit a set of observations as closely as possible. PEST also provides information about the sensitivity of the results to changes in the selected parameters, the correlation (a measure of non-uniqueness) among parameters, and the resolution of the parameters.

GMS is a widely used software package developed for the Army Corps of Engineers. GMS integrates and facilitates implementation of the conceptual model, interpretation of the output, and visualization of the results for all of the codes used in this effort. GMS also provides a convenient interface to link MODFLOW-2000 and PEST.

The overall objective of developing the two-dimensional flow model is to better understand both the regional- and local-scale features, investigate the validity of various calibration approaches, and investigate the feasibility of using all of the aquifer wells available inside the INL Site boundaries and the rest of the model domain as calibration wells. Another objective is to investigate the sensitivities of important model input parameters, such as hydraulic conductivity, underflow recharge rates from tributary drainage basins and the precipitation recharge rate, and their influence on the simulated head field at the local and subregional scale. Transient effects of the flow field on contaminant transport will be investigated in the next phase of the OU 10-08 modeling project. This could lead to a revision of the two-dimensional flow model.

The following subsections summarize the implementation of the conceptual model into a two-dimensional, steady-state numerical flow model using GMS/MODFLOW-2000. Topics discussed include domain selection, grid design and orientation, depth scenarios, boundary assignments, calibration approaches, calibration results, and limitations of the two-dimensional integrated model.

3.1.1 Model Domain Selection

This subsection discusses the domain size selection, domain boundary locations, and effective aquifer thickness scenarios. The physical extent, or domain, of any groundwater numerical model should be beyond the institutional boundaries of the subject facility being studied such that the simulated groundwater flow at the facilities is not affected by the model boundaries. Typically, physical boundaries, such as impermeable barriers, are used as model boundaries. But hydraulic boundaries, based on groundwater divides or streamlines, are also often used.

For the OU 10-08 model, groundwater flow is principally in a southwest direction. Model boundaries, therefore, generally lie to the northwest, southeast, northeast, and southwest. For the OU 10-08 project, the spatial extent of the model was chosen to correspond to natural physical boundaries to the northwest of the INL Site; hydraulic boundaries, based on streamlines, along the southeast; and hydraulic boundaries to the northeast and southwest.

The distance from the institutional boundaries of the INL Site to the natural boundaries northwest of the site is predetermined by the geologic nature of the mountain ranges intersecting the ESRP. The other boundaries, however, are open to interpretation. Factors influencing the location of the hydraulic boundaries include the need to provide adequate downgradient extent for risk assessment, a need to minimize overall domain size for computational efficiency, and interpretation of hydraulic head maps to determine fixed-head or no-flow conditions.

The initial model domain was selected based on then-current hydraulic head maps and the need to extend the model sufficiently downgradient. This domain is depicted in Figure 3-1. This domain covers nearly 7,770 km^2 (3,000 mi^2), as proposed initially in the OU 10-08 modeling strategy report (Arnett and Smith 2001). The domain is approximately 143 km (89 mi) along the general direction of groundwater flow, between 43 and 61 km (27 and 38 mi) in the transverse direction, and oriented along the principal axes of the Snake River Plain. This domain was incorporated into both the preliminary two-dimensional flow and two-dimensional transport models experimented with during fiscal year 2005.

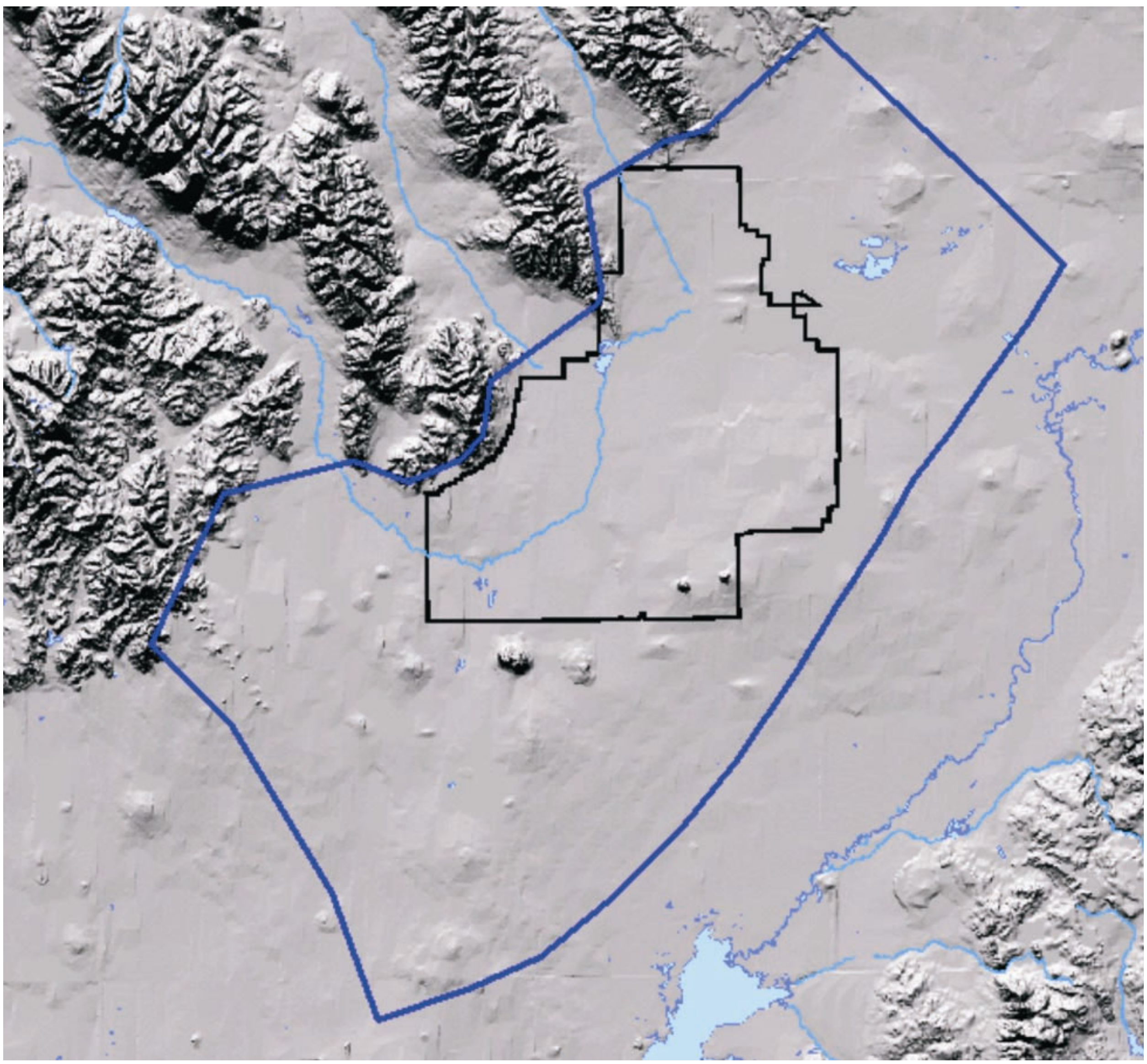


Figure 3-1. Initial OU 10-08 model domain.

The Mud Lake area in the northern part of the initial model domain is known to have very seasonally dependent head conditions with significant fluctuation. The available head measurements indicate a much higher groundwater elevation than the regional aquifer. Much of the groundwater in this area appears to be basically a perched water body. As a result, the placement of the northeast boundary was brought closer to the INL Site institutional boundary.

Additionally, inclusion in head maps of certain wells to the southwest of the OU 10-08 initial model domain demonstrated that a significantly steepening hydraulic gradient occurs in this area. However, this gradient is based on a very limited number of aquifer wells. Furthermore, analysis of streamlines resulting from the final mapping of June 2004 water levels indicates a somewhat different streamline near the southern end of the southeast boundary. As a result, the southwest boundary was slightly modified by truncating the southeastern corner of the original model domain.

The resulting new model domain is shown in Figure 3-2. This domain now covers approximately 2,500 mi^2, with boundary lengths of 101, 51, 109, and 68 km (63, 32, 68, and 42 mi) along the southeast, northeast, northwest, and southwest sides, respectively.

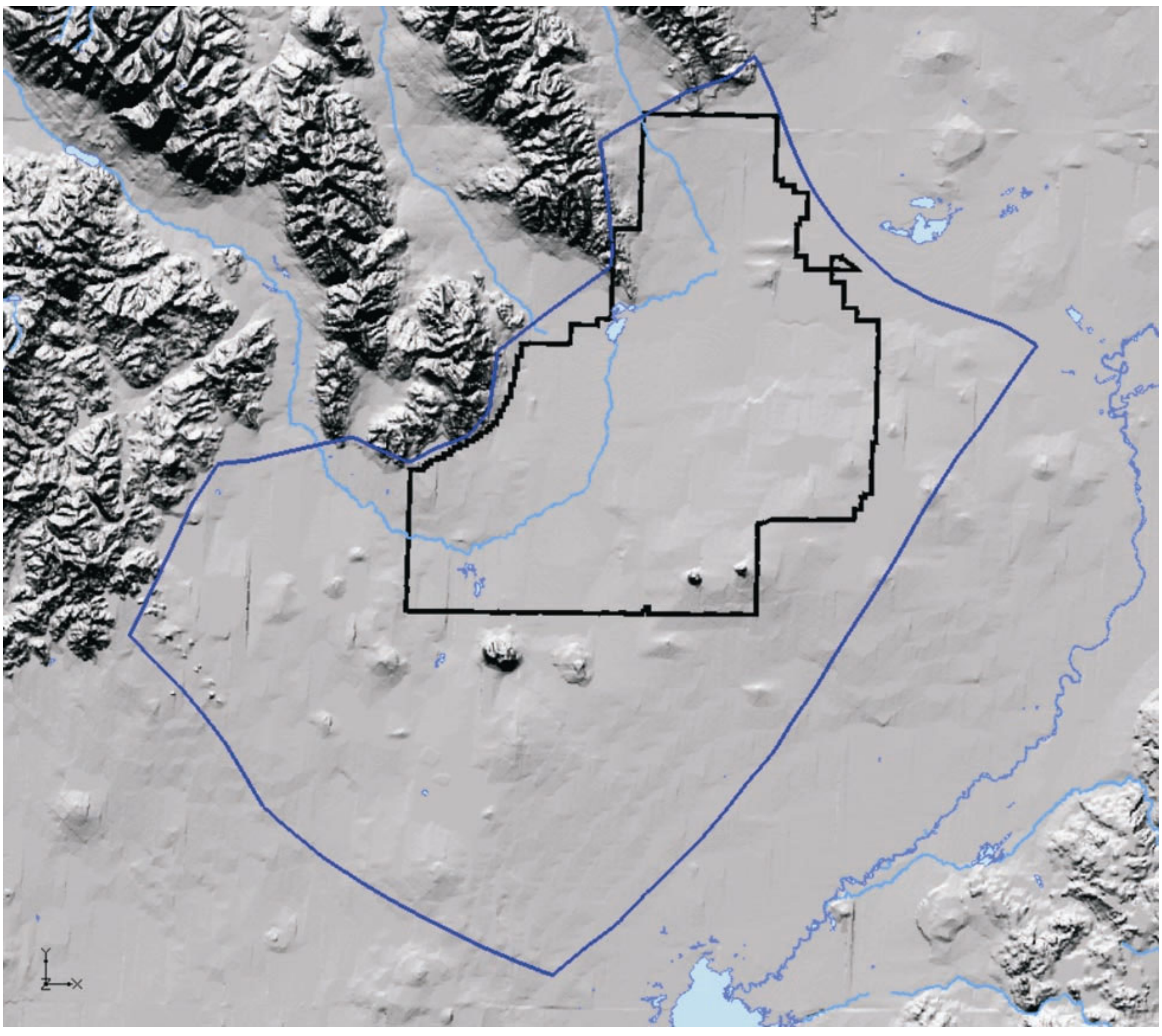


Figure 3-2. New two-dimensional flow model domain.

In the vertical direction, the model domain extends to the top of the aquifer, or water table surface, as determined from aquifer well water-level measurements such as those obtained in June 2004 and June 2005. This elevation and surface configuration are described in detail in Section 2, with a final elevation contour map provided in Figure 2-28.

The lower surface of the model domain is defined by the thickness of the active portion of the aquifer. The aquifer thickness has been previously determined from an integration of temperature-profiling and electrical-resistivity studies. As described in the OU 10-08 work plan (DOE-ID 2004), two thickness scenarios have been considered for the flow and transport modeling activities of fiscal year 2005. The thickness scenarios include both a thick and a thin version. They are based on different interpretations of trends observed in electrical-resistivity and thermal-profile data that are used to delineate the bottom of the aquifer. Both use the limited direct evidence of the aquifer base from the eight deep wells in the south-central part of the study area and extrapolate differently to the perimeter of the model domain using electrical-resistivity data and water temperature at the top of the aquifer. The thick interpretation uses colder water temperatures to infer thicker areas of the aquifer toward the north of the model domain and electrical-resistivity observations of a very thick aquifer section downgradient of the INL Site. The thin scenario only infers a general tendency for the aquifer to thicken toward the center of the Snake River Plain. Images depicting these two thickness scenarios are presented later in Subsection 3.1.4 (Figures 3-4 and 3-5).

3.1.2 Boundary Conditions

Figure 3-3 shows the locations and types of boundary conditions implemented in the two-dimensional flow model. The northern and southern boundaries of the OU 10-08 model domain are currently treated as specified head boundaries. The contour map of the June 2004 water table map shown in Figure 2-28 was used to assign head values along these two specified head boundaries.

The eastern boundary of the OU 10-08 model domain extends in a northeast-to-southwest direction and corresponds to an estimated groundwater flow line across which there is no groundwater flow. The preliminary model domain is bounded on the west by a Type 2 boundary (part no-flow and part specified-flux) that represents mountain ranges and the mouths of important tributary drainages. The toes of mountain ranges are assumed to minimize groundwater movement in and out of the model domain and are, therefore, modeled as no-flow (zero-flux) boundaries. Between these mountain ranges, specified-flux boundary conditions are used to model the underflow recharge from tributary drainage basins. The flux estimates were derived from the USGS regional aquifer model studies (Kjelstrom 1986; Garabedian 1992) and subjected to sensitivity study. Table 3-1 summarizes the underflow recharge fluxes implemented in the two-dimensional flow model. These estimated fluxes are highly uncertain, and a comprehensive sensitivity study discussed later in this report will be carried out.

Table 3-1. Underflow recharge flux from tributary drainage basins.

	Estimated Mean Underflow Flux		
Basin Name	m^3/d	m^3/s	ft^3/s
Big Lost River	882,122	10.2	361
Little Lost River	554,284	6.4	227
Birch Creek	250,104	2.9	102

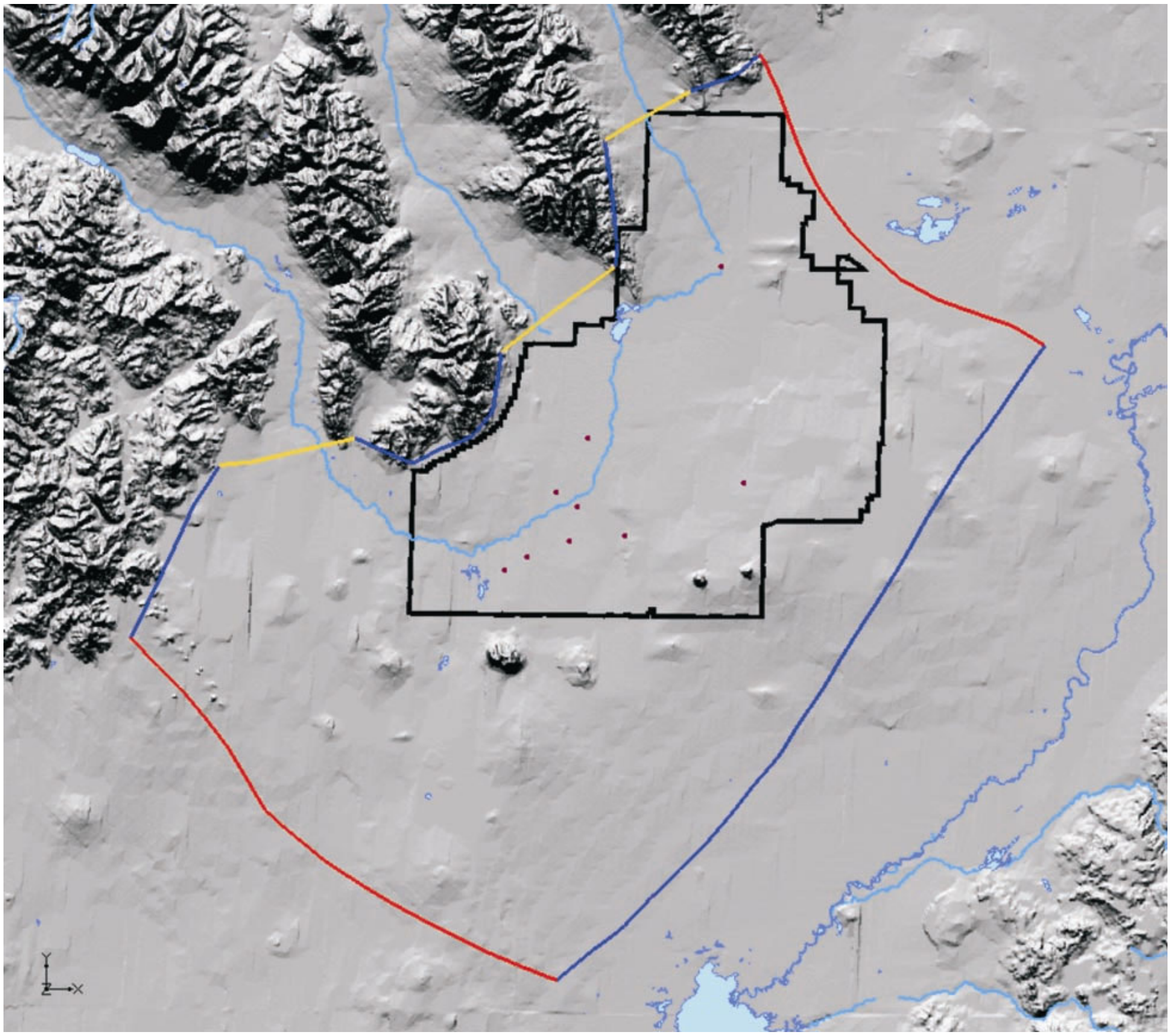


Figure 3-3. Boundary types of the two-dimensional flow model. (Red indicates the specified head boundary, blue indicates the no-flow boundary, and yellow indicates the specified-flux boundary.)

3.1.3 Sources and Sinks to the Flow Model

Within the new model domain described in Subsection 3.1.1, several sources and sinks of groundwater exist. Sinks are limited to pumping well discharge. Within the model domain, approximately 30 production or potable water wells are active. For potable water wells, it is assumed that the pumping rates are minor and groundwater consumption is minimal. For the production wells at major facilities, pumping can be quite significant, up to 0.044 m^3/s (1E + 6 gal/d). However, the pumping rates and times of pump operation for these wells are not well recorded; furthermore, it is assumed that all of the groundwater produced by these wells returns to the aquifer, because the production well water is, in all cases, discharged to disposal ponds. As such, no sinks are included in the numerical two-dimensional flow model at this point.

Sources include infiltration recharge from the Big Lost River, an ephemeral surface water feature that flows into areas simulated within the new two-dimensional model domain. For this version of the two-dimensional flow model, the Big Lost River was simulated as a specified-flow boundary with a constant flux of 243,344 m^3/d (100 cfs) that was variably distributed along the entire reach, which enters the new model domain along the west boundary in the vicinity of Arco and terminates in the Big Lost Sinks southwest of TAN.

Areal precipitation falling within the new model domain constitutes another source of recharge. For this source, the two-dimensional model receives across the top boundary (water table) a constant flux of 1.95E-5 m/d (0.28 in./yr) of infiltration to represent the average of the 2 to 5% of precipitation estimated by Cecil et al (1992). This is currently uniformly distributed across the new model domain.

3.1.4 Construction of the Numerical Grid

The size of the nodal spacing in the horizontal dimension is a function of the expected curvature in the water table or potentiometric surface (Anderson and Woessner 1992). Finer nodal spacing is required for highly undulated water tables. Spatial variation of the hydraulic parameter should also be considered in the selection of node spacing. Currently, the minimum base node spacing used in any of the three existing individual WAG models is 305 m (1,000 ft) in the WAG 7 groundwater model, but each WAG model also has local refinements with smaller node spacing.

For instance, the WAG 7 model is refined near the Subsurface Disposal Area of the RWMC with a grid spacing of 152 m (500 ft). The WAG 3 groundwater model has a base grid spacing of 400 m (1,312 ft) and is refined to 200 m (656 ft) within facility boundaries. The WAG 1 groundwater model has a 1,600-m (5,249-ft) base grid spacing and 25-m (82-ft) refined spacing, resulting from a six-layer telescopic refinement scheme. Some optimization will be required to find the ideal grid spacing; spacing that is too coarse will fail to capture groundwater flow, but spacing that is too fine will result in an unwieldy number of grid cells and reduced computational efficiency.

It is anticipated that a variable grid spacing scheme will be required. Toward the margins of the model, the grid spacing will be largest, because these areas are farthest from the individual WAGs. Local refinements will be made at the portions of the model corresponding to the individual WAGs. Figures 3-4 and 3-5 show the two-dimensional, single-layer grid that we implemented in the two-dimensional numerical model for the two thickness scenarios. The grid has a minimum size of 492 ft (150 m) near nine individual WAGs and a maximum size of 2,460 ft (750 m) elsewhere inside the model domain. Such discretization results in a total of 53,658 grid cells. MODFLOW uses a structured grid discretization. As a result, local refinements made at individual WAGs must be carried throughout the model in both grid alignment directions. The grid is rotated by 45° to align with the main flow direction in order to save computational time.

3.1.5 Selection of the Calibration Targets

The OU 10-08 flow model will provide regional- and local-scale groundwater flow fields for the integration of groundwater flow and transport modeling results from individual WAGs. The flow velocity is the primary parameter of importance. Typically, measured heads and head gradients are the targets used to calibrate flow models.

The primary calibration target for this two-dimensional flow model is hydraulic head (i.e., hydraulic potential) measured in aquifer wells. Ideally, the set of primary calibration targets or head values should represent the same period in time. This is due to head values being subject to barometric fluctuations and changes due to recharge or discharge. The data collected from the June 2004 water-level measurements were used for the fiscal year 2005 two-dimensional flow model calibration.

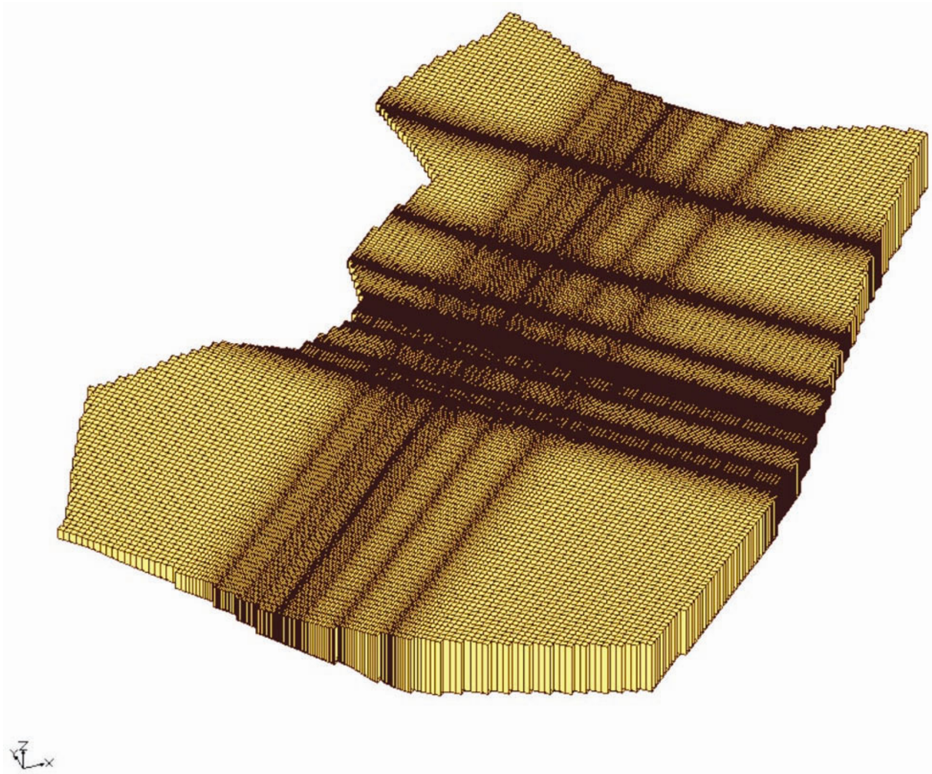


Figure 3-4. The two-dimensional, single-layer grid for the “thick” aquifer scenario.

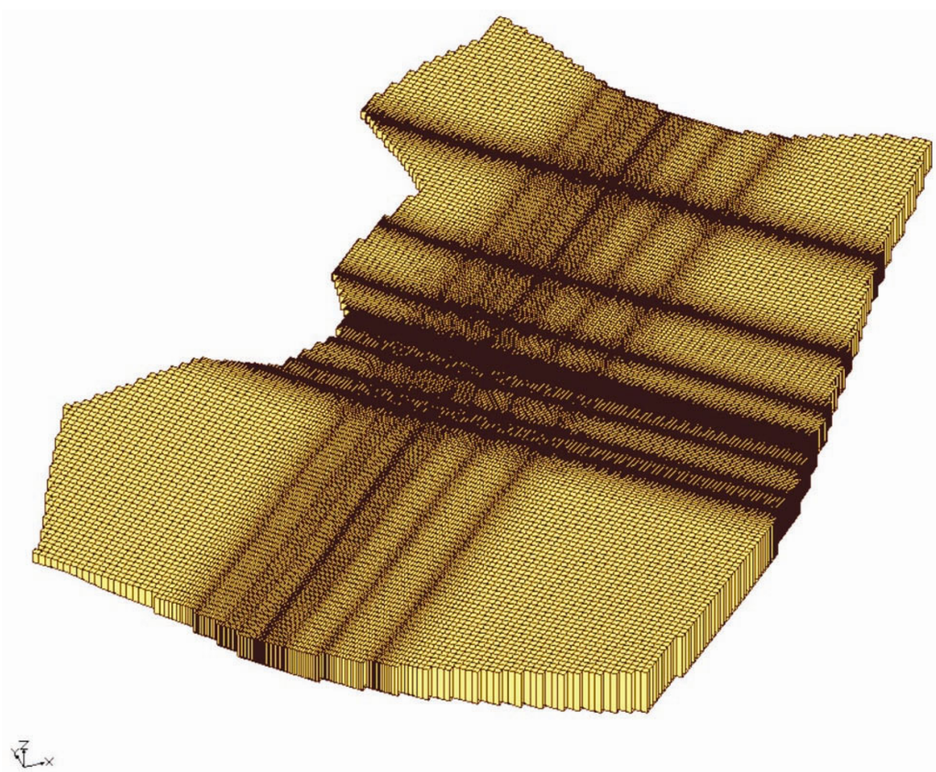


Figure 3-5. The two-dimensional, single-layer grid for the “thin” aquifer scenario.

The previous WAG 10 SWGM (McCarthy et al. 1995) used a limited subset of available spring 1980 water-level data. A total of 21 key wells were selected and supplemented by an additional 27 wells that were weighted less in that model's calibration scheme. Initially, all aquifer water-level measurements collected by Idaho Cleanup Project personnel in June 2004 from wells within the model domain were considered as calibration targets for the fiscal year 2005 two-dimensional flow model. The June 2004 water-level measurement effort included 229 aquifer wells; however, 15 of these were found to be completed at significantly deeper depths than the mean completion depth of the aquifer well set. Although the data are useful for examining the potential for vertical gradients, they were not included as part of the calibration set for the two-dimensional flow model.

Of the remaining 214 wells measured by INL Site contractors in June 2004, seven water-level measurements were replaced with USGS measurements, because inaccuracies were found in some of the INL-collected data points. Furthermore, this set of 214 wells was supplemented with additional USGS wellhead data that were collected from 10 wells; these wells are located along the outer edges of the model domain and are not typically measured by INL Site contractors. Though not used in calibrating the model, an additional 119 water levels from wells located outside the model domain were used for controlling contour lines in the creation of the water table map presented in Figure 2-28.

The new domain is smaller than the initial domain, so the 214-well set used to calibrate the two-dimensional flow model within the new model domain (described in Subsection 3.1.4) is smaller than the 253-well set used to calibrate the two-dimensional flow model with the initial domain. The land-surface elevation of the 214-well calibration set ranges over 565 ft (172 m) from a minimum of 4,112 ft (1,243 m) to 4,677 ft (1,425 m). These elevations are feet above mean sea level (National Geodetic Vertical Datum of 1929). Figure 3-6 illustrates the location of the 214 wells relative to the new model domain.

Figure 3-7 illustrates an important sensitivity of the model to the number of wells that are used in the calibration process. Similar to the previous WAG 10 model (McCarthy et al. 1995), the fiscal year 2005 two-dimensional flow model was initially calibrated using a smaller subset of 70 key wells. This resulted in very minimal overall error between simulated and observed heads. However, the model was later calibrated with the initial model domain using 253 wells. Particle tracking using the MODPATH feature of GMS allowed examination of resulting flow paths. Figure 3-7 shows that adequate approximation of the flow field is achieved with the 253-well calibration. The resulting flow paths in the vicinity of INTEC are oriented more to the south and are more consistent with those obtained from the local-scale OU 3-14 groundwater model. Additional model sensitivities are discussed in Subsection 3.1.10.

The use of more than four times as many calibration targets represents the difference in two important calibration approaches, zonation versus pilot point. In this study, three calibration techniques have been explored and applied. The three calibration techniques are zonation with automated parameter estimation, automated parameter estimation using the "pilot-point" approach, and a combination of these two methods. Each method has advantages and disadvantages. All three methods were applied, and the method that produced the best results was selected as the final calibration method. These approaches and their results are described briefly in the following subsections.

3.1.6 Zonation Approach for Groundwater Flow Model Calibration

The zonation approach is the traditional method of calibration; this approach divides the model domain into zones of constant property value. The main steps in the process are as follows:

- The model domain is divided into zones of equal hydraulic conductivity. Each zone of hydraulic conductivity is defined by a different parameter with a constant model parameter value.

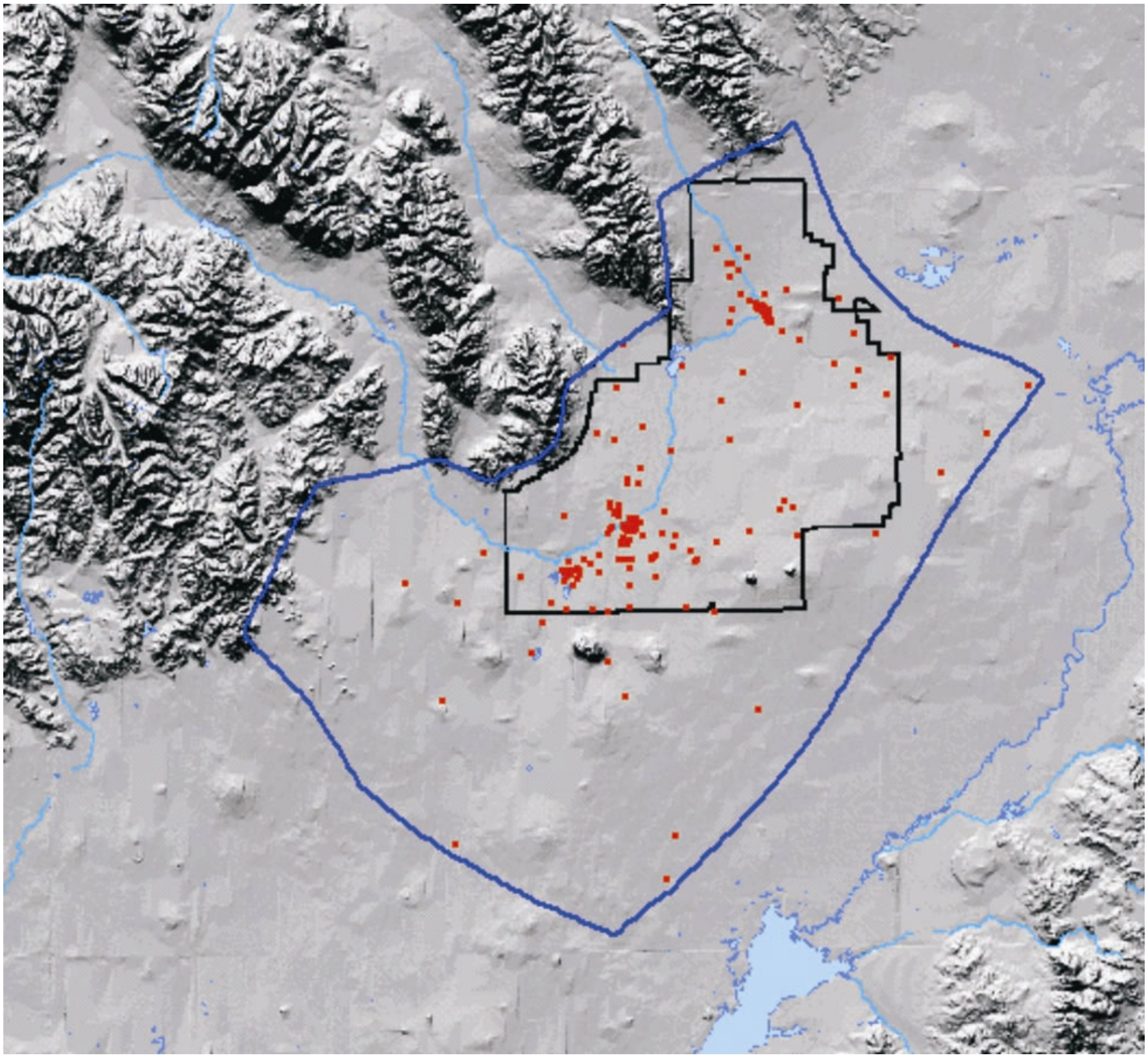
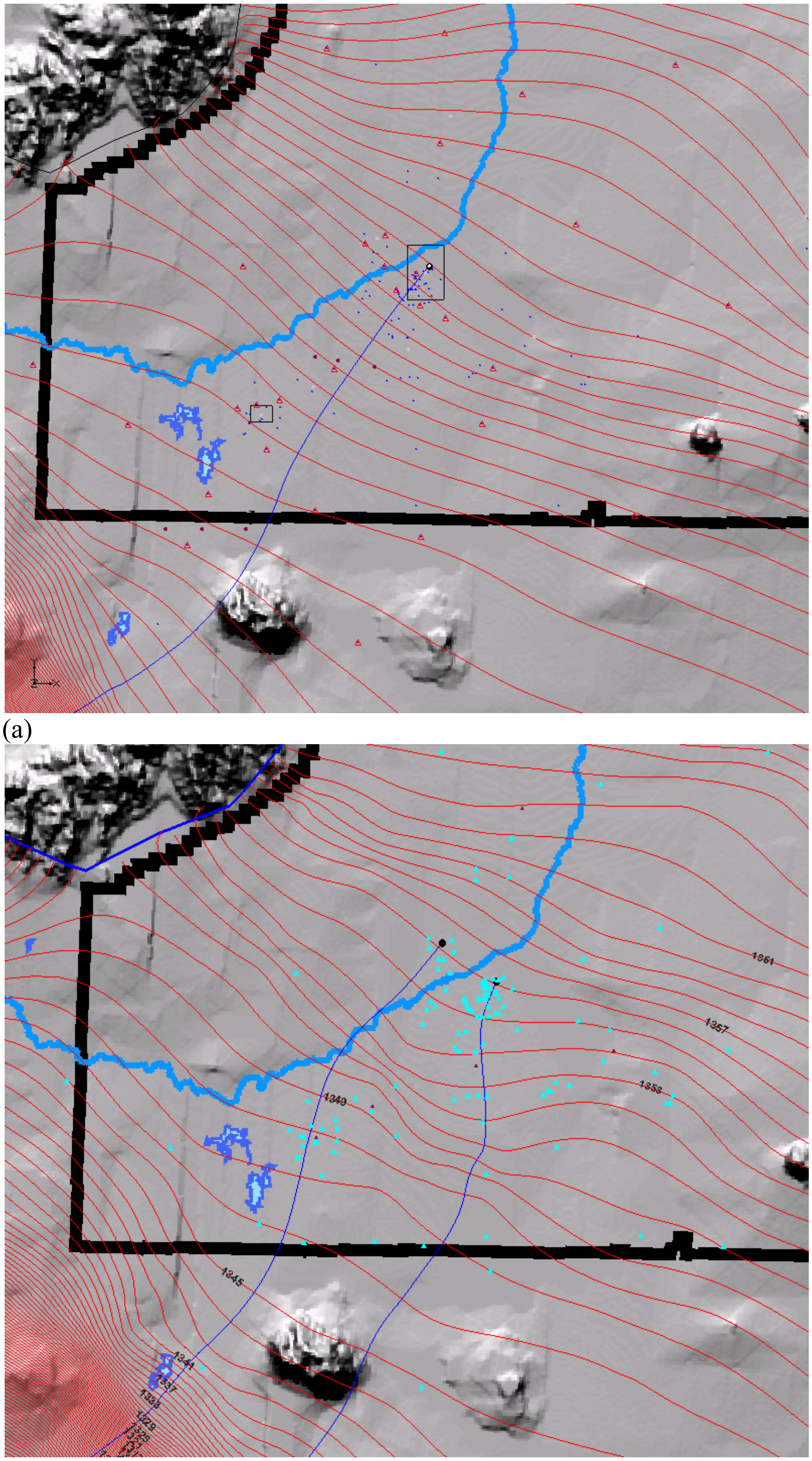


Figure 3-6. New model domain showing the locations of 214 aquifer wells (red dots) that were used as calibration targets in fiscal year 2005.



(a)

(b)

Figure 3-7. Comparison of simulated flow paths that are the result of two-dimensional flow model calibration using head data from (a) only 70 wells (red dots) and (b) 253 wells (light blue dots).

- Initial hydraulic conductivity estimates are made for each zone.
- PEST is utilized to automatically adjust the hydraulic conductivity values of a selected set of hydraulic conductivity zones and, therefore, minimize the weighted sum of the squared simulation errors over all of the hydraulic head measurements.

The zonation approach was applied to the two-dimensional flow model calibration process in fiscal year 2005 with limited success. The results of this approach, as well as the results of other approaches, are discussed in a Subsection 3.1.9.

3.1.7 Pilot-point Approach for Groundwater Flow Model Calibration

The pilot-point approach also utilizes PEST automated parameter adjustment, but instead of beginning with zones of constant parameter value, the approach uses arbitrarily positioned pilot points. The steps in this approach are as follows:

- A set of points is selected inside the model domain as pilot points.
- Initial estimates of hydraulic conductivity are assigned for each pilot point.
- PEST is used to automatically adjust the hydraulic conductivity values of pilot points to minimize the weighted sum of the squared simulation errors over all of the hydraulic head measurements. The results of a PEST run consist of a set of optimal hydraulic conductivity values at pilot points that provide the best fit of the flow model to the hydraulic head measurements being used for calibration. The hydraulic conductivity values of the rest of the model domain are obtained by interpolating those optimal conductivity values at pilot points.

One advantage of the pilot-point approach is that it provides a smoothly varying and heterogeneous conductivity map without arbitrarily defining hydraulic conductivity zones. Another advantage is that this method can directly incorporate aquifer test data as a subset of pilot points, with fixed hydraulic conductivity values inferred from those tests.

The disadvantage of the pilot-point approach is that it is difficult to incorporate lithologic information when available. Therefore, we planned to use the following coupled pilot-point/zonation calibration approach, which has advantages of both approaches.

3.1.8 Coupled Pilot-point/Zonation Approach for Groundwater Flow Model Calibration

Another calibration method implemented in fiscal year 2005 for the two-dimensional flow model is a combination of the two previously discussed approaches. The coupled pilot-point/zonation calibration approach bounds upper and lower limits of possible pilot-point values via the zonation approach, thus taking advantage of known geologic features. The steps in this method are as follows:

- Hydraulic conductivity zones are defined according to available lithology and hydrostratigraphic information.
- Zones are selected where additional variation within zones is desired, and pilot points are set up within them. The hydraulic conductivity values at pilot points of a particular zone are bounded by the range of hydraulic conductivity appropriate for that particular zone’s lithology.
- Uniform hydraulic conductivity values are assigned to zones without pilot points.
- Hydraulic conductivity values are assigned to pilot points.

- PEST is utilized to adjust the hydraulic conductivity values of each pilot point and for zones without pilot points.

The output of PEST will be a conductivity map that consists of zones with a constant hydraulic conductivity value and zones with varying hydraulic conductivity values. This feature may be important for the transport model to reproduce the observed plume migration behaviors, because local-scale heterogeneity largely affects plume migrations. The coupled pilot-point/zonation approach provides a good combination of the large-scale heterogeneity (from zone to zone) and local-scale heterogeneity (inside a zone). For the OU 10-08 numerical model, we started with the zonation approach followed by the pilot point and coupled pilot-point/zonation approaches. The approach that is most efficient and most realistically reflects field hydrogeological settings will then be used for the future three-dimensional model calibrations.

3.1.9 Calibration Results

The following subsections provide the hydraulic head mismatch, parameter value ranges, and a discussion on parameter reliability. The calibration results from all three approaches are compared and discussed below.

3.1.9.1 Zonation Approach. The fiscal year 2005 modeling effort considered two different aquifer thickness scenarios, thick (Figure 3-4) and thin (Figure 3-5), within this calibration effort. Figure 3-8 shows the hydraulic conductivity zones derived mainly from the large-scale geological settings. Table 2-1 summarizes the large-scale geologic features associated with each zone and the conductivity value ranges based on pumping test data.

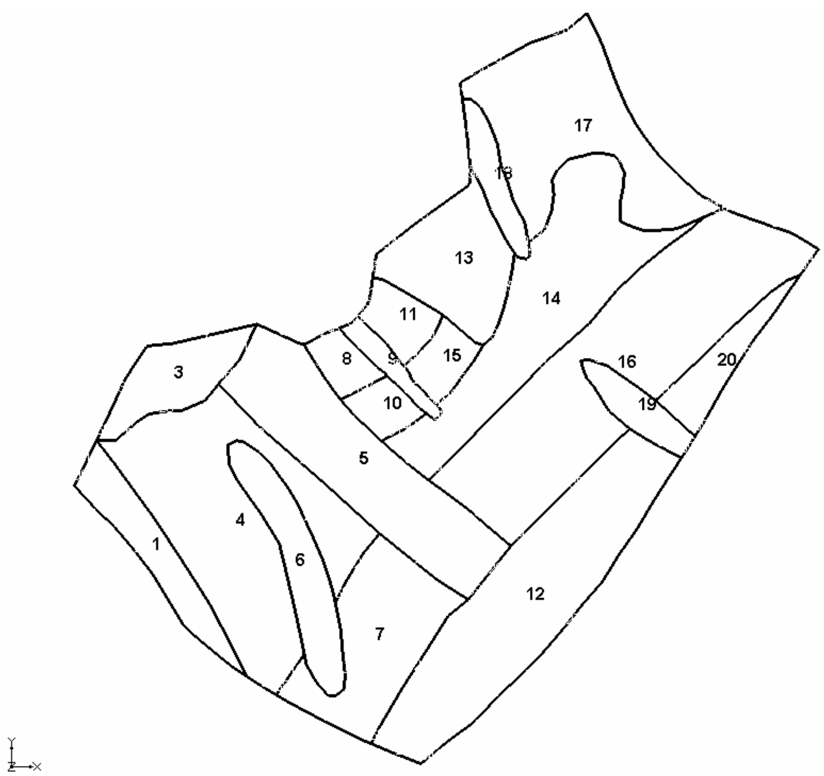


Figure 3-8. Hydraulic conductivity zone map implemented in the two-dimensional flow model.

Such a hydraulic conductivity zone map caused very irregular head distributions near the southern portion of the model domain, particularly in Zones 4, 6, and 7, so they were combined during the calibration process. The following results indicate that such treatment yields a better head contour map that is much closer to the measured groundwater table.

Figure 3-9 shows the simulated hydraulic head contour map and residuals at all observation wells for thick and thin aquifer scenarios. Figure 3-10 shows the residuals for wells near facilities for both scenarios. As shown in these figures, large mismatches occurred at wells in the northern and southern portion of the model domain, wells near INTEC, and wells in the central portion of the INL Site. Despite large residuals for both scenarios, the simulated head fields are able to reproduce the large-scale features of the measured water table, as shown in Figure 2-28.

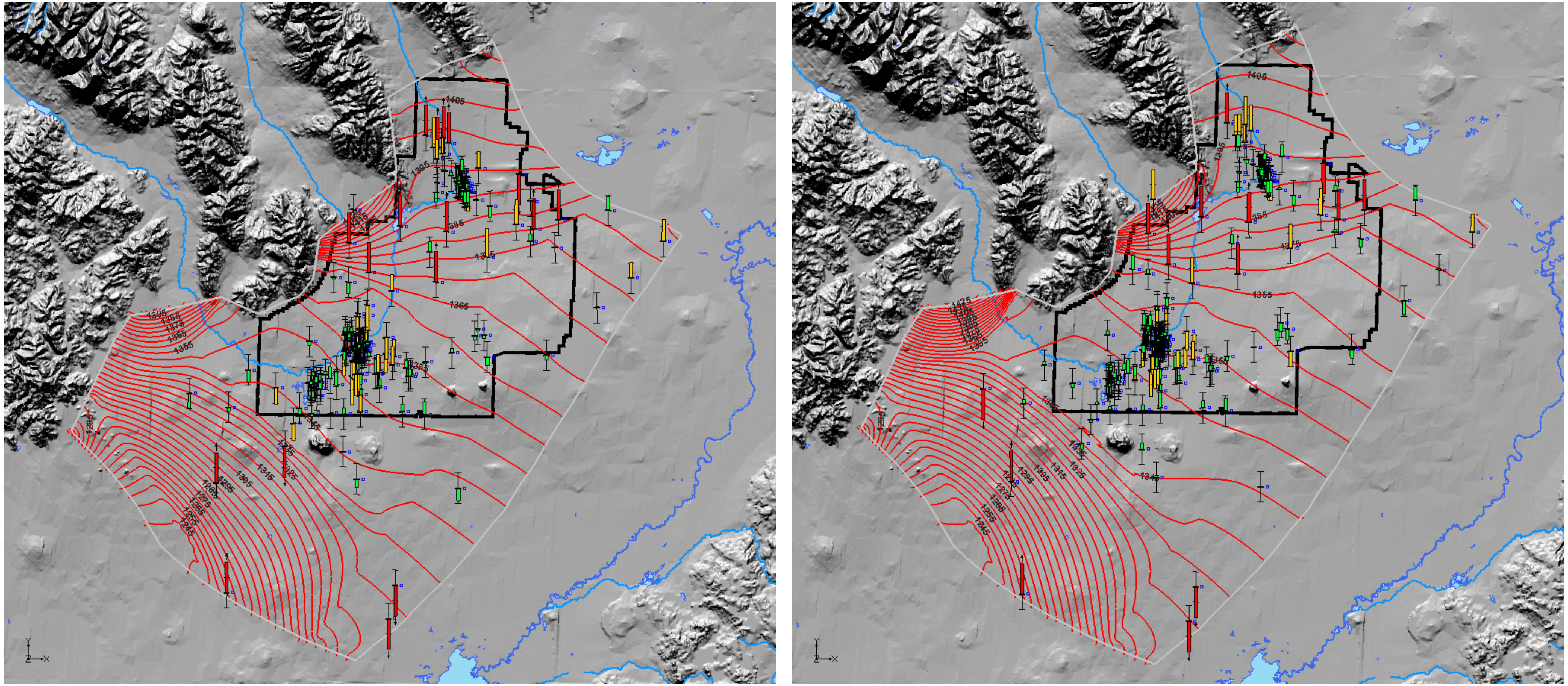
For both aquifer thickness scenarios, a number of observation wells south of INTEC, north of TAN, and near the central portion of the INL Site have large mismatches; some of them are quite high. Figure 3-11 shows the plots of residuals versus observed heads for both aquifer thickness scenarios. For both scenarios, residuals are randomly distributed, and no systematic bias is observed in these two plots. The large residuals are unacceptable in terms of accurate description of the flow field inside and near the INL Site.

Figure 3-12 shows the comparison of the estimated hydraulic conductivity maps between the two aquifer thickness scenarios. Visual comparison between the two maps reveals some differences in the magnitude of the estimated K values for a number of zones. However, the overall K value distribution patterns are similar for both scenarios.

Because two different thickness scenarios are considered, it is interesting to see the transmissivity field for both scenarios. Figure 3-13 shows the transmissivity fields by multiplying the estimated K field with the effective aquifer thickness. Despite some differences between the estimated K maps, the transmissivity fields for both scenarios look similar. This indicates that, from a perspective of inverse modeling for a two-dimensional flow model, the thickness of the aquifer does not really matter. Although the fiscal year 2005 two-dimensional model includes variable aquifer thickness, only transmissivity really matters in terms of affecting simulated head contour maps.

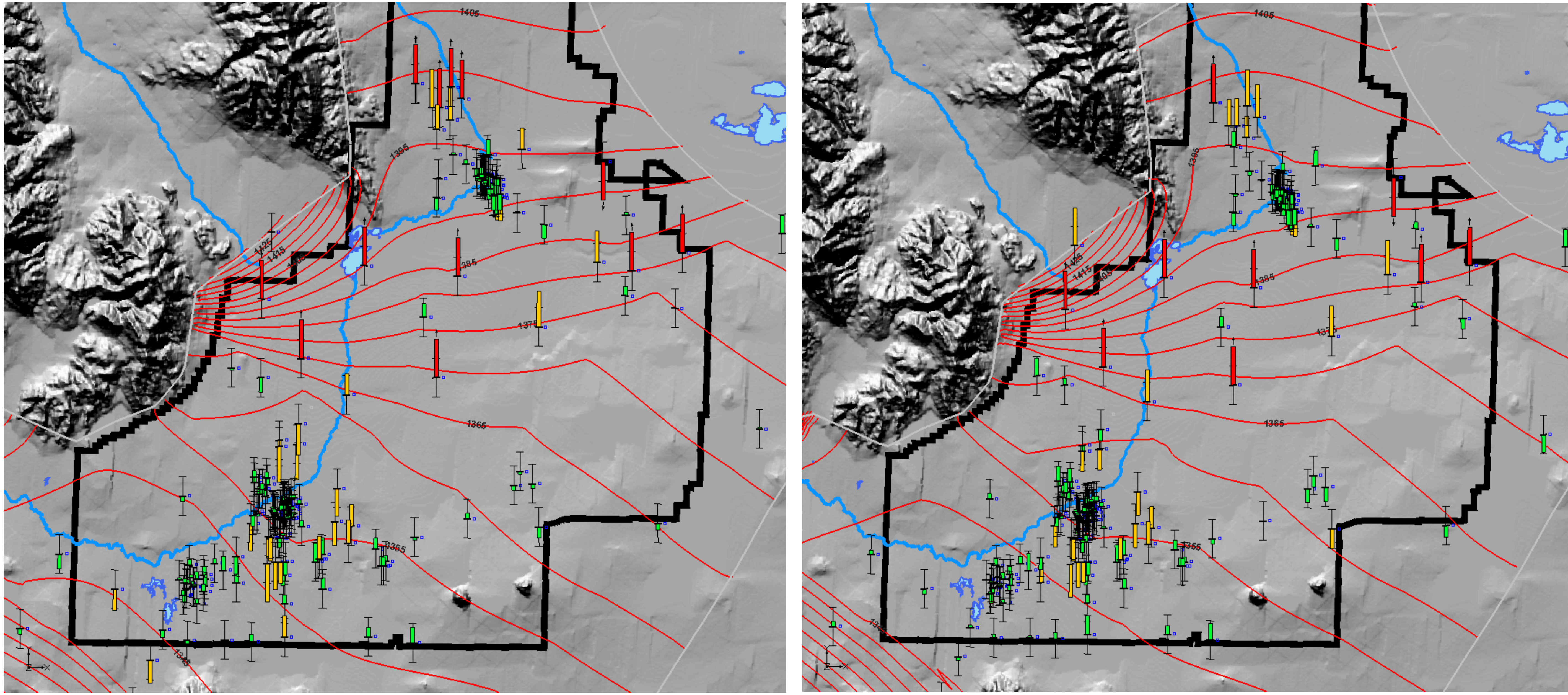
PEST also automatically calculates the confidence bounds of the estimated parameters as an indicator of parameter uncertainty. Tables 3-2 and 3-3 show the estimated K value for each zone and the associated 95% confidence bounds of each estimate for the thick and thin scenarios, respectively. As shown in these tables, the confidence bounds for most estimated parameters span two to seven orders of magnitude, an indicator of large uncertainty associated with the estimated parameter values. The largest uncertainty occurs in Zones 1 and 3, where no observation wells are located. Other results, including the sensitivities of the parameters, will be further discussed in Subsection 3.1.10.

In summary, the current zonation approach based on the knowledge of large-scale geological features is able to reproduce the large-scale features of the measured water table. However, the current zonation approach is unable to produce satisfactory matches to the measured heads, particularly the heads measured near facilities. In addition, the estimated parameters for both aquifer thickness scenarios exhibit large uncertainties, indicating that the estimated parameter values are poorly resolved during the inversion process. Further refinement of the current K zone map is necessary to obtain more satisfactory matches to the measured heads, which is critical in accurately predicting the flow path of contaminant.



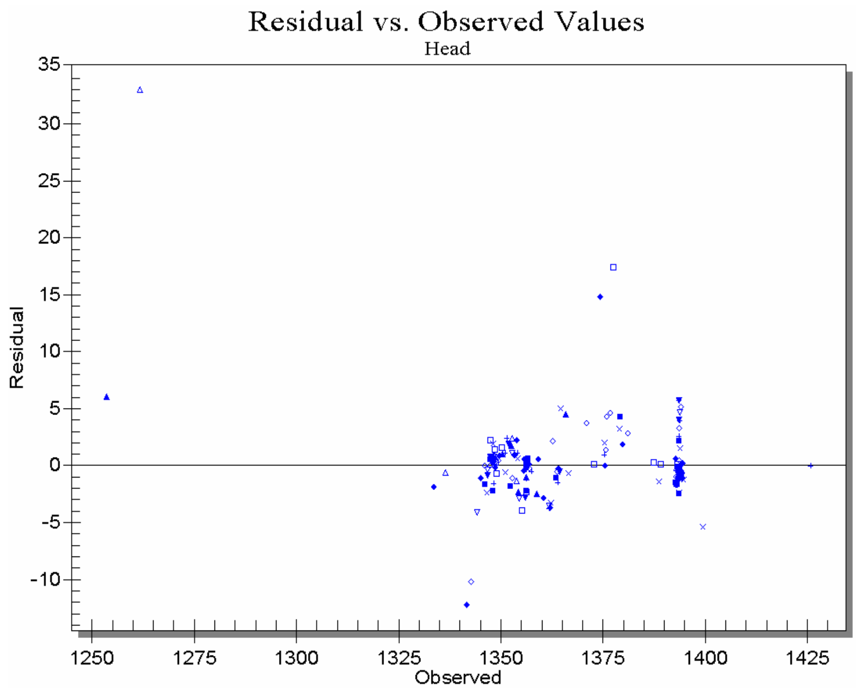
(a) (b)

Figure 3-9. Simulated head contour map and simulation residuals at observation wells for (a) the thick aquifer scenario and (b) the thin aquifer scenario (red is > 3 m, yellow is 2 to 3 m, and green is < 2 m).



(a) (b)

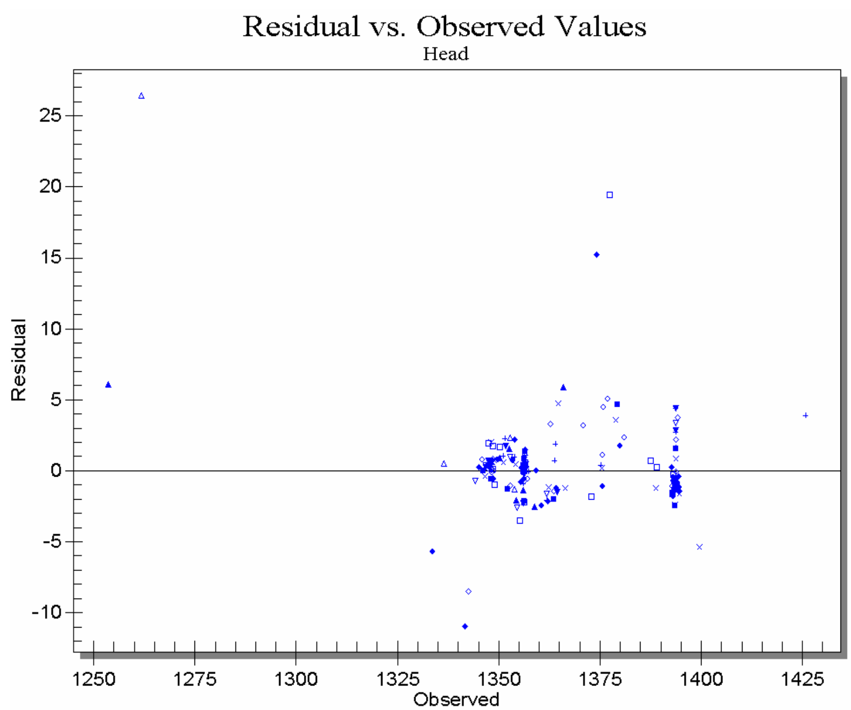
Figure 3-10. Simulated head contour map and simulation residuals at observation wells inside the INL Site for (a) the thick aquifer scenario and (b) the thin aquifer scenario (red is > 3 m, yellow is 2 to 3 m, and green is < 2 m).



Mean Error: 0.285 m

Mean Abs. Error: 1.543 m

Root Mean Sq. Error: 3.363 m

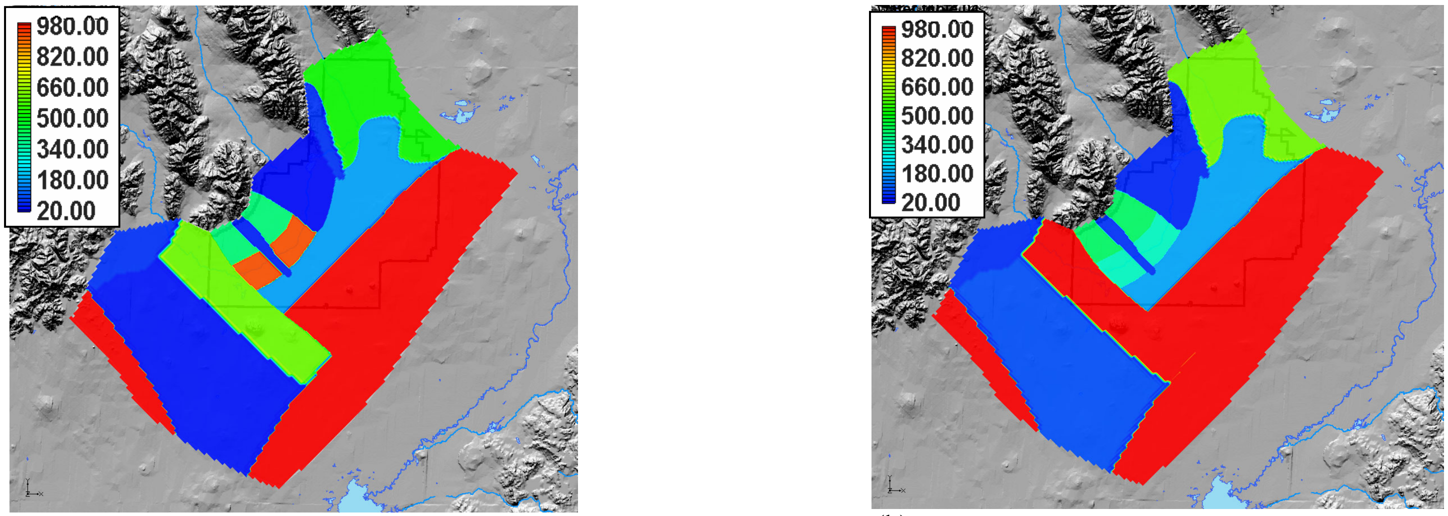


Mean Error: 0.240 m

Mean Abs. Error: 1.521 m

Root Mean Sq. Error: 3.069 m

Figure 3-11. Residual versus observed head values for the thick aquifer scenario (top) and the thin aquifer scenario (bottom).



(a) (b)

Figure 3-12. The estimated hydraulic conductivity field (in m/d) for (a) the thick scenario and (b) the thin scenario.

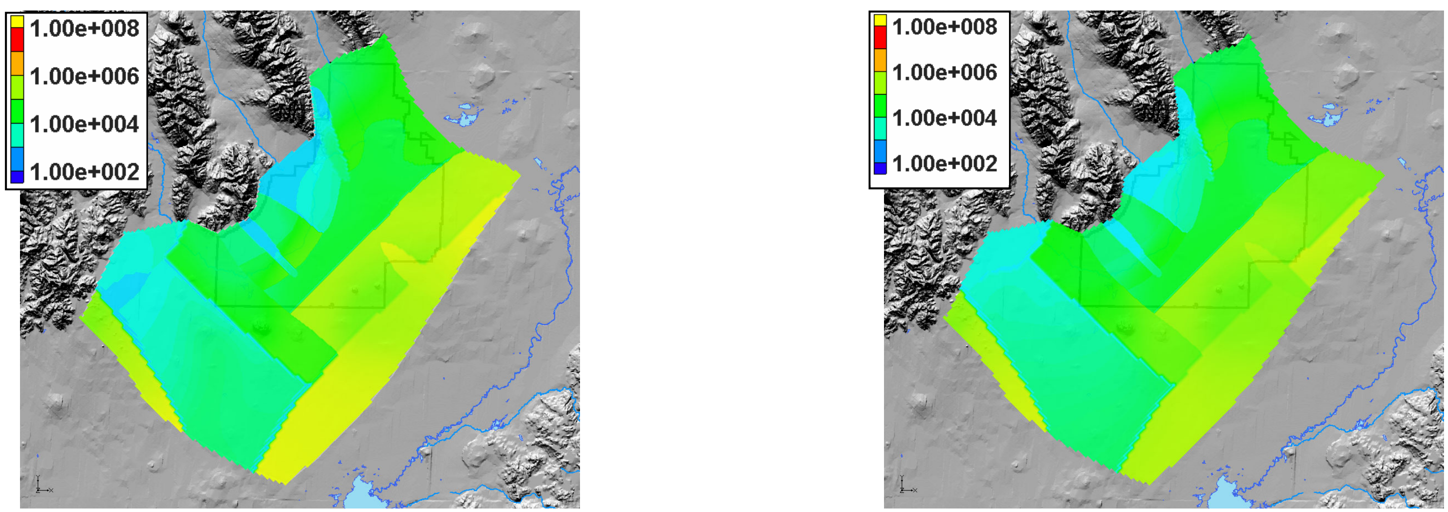


Figure 3-13. The estimated transmissivity field for the thick scenario (left) and the thin scenario (right).

Table 3-2. Estimated K values and associated 95% confidence bounds for the thick aquifer scenario.

Parameter[a]	Estimated Value (m/d)	Lower limit (m/d)	Upper limit (m/d)
Zone 3	8.73E+01	6.63E-05	1.15E+08
Zone 1	8.00E+03	4.05E-01	1.58E+08
Zone 4	6.01E+01	2.43E+01	1.49E+02
Zone 17	5.32E+02	6.70E+01	4.22E+03
Zone 18	8.90E+01	2.61E+00	3.04E+03
Zone 5	6.24E+02	2.30E+02	1.69E+03
Zone 13	4.87E+01	4.24E+01	5.59E+01
Zone 8	4.06E+02	1.91E+02	8.66E+02
Zone 9	7.15E+01	2.79E+01	1.83E+02
Zone 14	1.95E+02	3.06E+01	1.25E+03
Zone 10	9.23E+02	2.90E+01	2.94E+04
Zone 16	2.96E+03	3.83E+02	2.29E+04
Zone 19	6.56E+03	2.81E+02	1.53E+05
Zone 12	6.25E+03	7.73E+02	5.05E+04
Zone 20	6.10E+03	2.25E+02	1.65E+05

a. Zones 6 and 7 are tied with Zone 4; Zone 11 is tied with Zone 8; and Zone 15 is tied with Zone 10.

Table 3-3. Estimated K values and associated 95% confidence bounds for the thin aquifer scenario.

Parameter[a]	Estimated Value (m/d)	Lower Limit (m/d)	Upper Limit (m/d)
Zone 3	5.60E+01	2.04E-04	1.54E+07
Zone 1	8.00E+03	5.41E-03	1.18E+10
Zone 4	8.89E+01	4.05E+01	1.95E+02
Zone 17	6.19E+02	1.19E+02	3.21E+03
Zone 18	4.86E+01	3.59E+00	6.58E+02
Zone 5	1.15E+03	3.26E+02	4.06E+03
Zone 13	4.87E+01	4.37E+01	5.42E+01
Zone 8	4.05E+02	2.15E+02	7.63E+02
Zone 9	6.13E+01	1.39E+01	2.70E+02
Zone 14	1.75E+02	4.59E+01	6.70E+02
Zone 10	3.13E+02	3.74E+01	2.62E+03
Zone 16	2.02E+03	3.84E+02	1.07E+04
Zone 19	2.98E+03	1.06E+02	8.43E+04
Zone 12	3.27E+03	5.94E+02	1.79E+04
Zone 20	5.69E+03	3.42E+02	9.45E+04

a. Zones 6 and 7 are tied with Zone 4; Zone 11 is tied with Zone 8; and Zone 15 is tied with Zone 10.